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PHOTOMETRY; FIELD BRIGHTNESS AND EYE ADAPTATION

W. E. FORSYTHE AND E. Q. ADAMS

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Light—which has been defined by the Illuminating Engineering Society[1] as radiant energy evaluated according to its capacity to produce visual sensation—is the all-prevading phenomenon which makes seeing possible, and its measurement is one of the tasks of physicists. Photometry—the art of measuring light—is very old. This art is described in the early writings of both Bouguer and Lambert in the 18th century. They described the photometers then in use and outlined many of the laws of photometry. Modern photometry may be said to have been introduced with the carbon-filament incandescent lamp, since this was the first source of light that could be held constant enough to make accurate measurement possible. Before a physicist is satisfied that he knows much about any phenomenon he must measure it; that is, he must evaluate it in terms of some selected standard, the standard being selected in relation to some characteristic of the phenomenon studied. This is as true for the output of a light source as for any other phenomenon, but here another characteristic enters. Since the output of the light source is used to enable the eye to function, the characteristics of the eye as the evaluator of radiant energy must be considered.

If the intensity of the radiation to which the eye is exposed becomes too high, the eye has several mechanisms, such as the iris diaphragm, the eyebrows, the eyelashes, and the eyelids, to reduce the intensity that reaches the retina, and in addition, the retina has a method of reducing its sensitivity when the intensity of the radiation reaching it is increased and of increasing its sensitivity when the intensity of this radiation is reduced. This is very fortunate since it enables us to see with ease over a very wide range of brightnesses.

Up until a few years ago physicists and engineers were, in general, interested in the performance of the eye as a measuring instrument for radiation only for brightnesses in ordinary ranges; that is, brightnesses centering around one to ten millilamberts*. A few physicists for theoretical reasons made some studies of the action of the eye at low levels of illumination. In the past few years, due to necessary considerations under blackout conditions, the performance and sensitivity of the eye under very low levels of field brightness became of interest.

When one studies the eye as a measuring instrument the first thing noticed is that the eye is a very poor, if not an almost helpless, device to use alone to

* A Lambert is a unit of brightness equal to $1/\pi$ candle per square centimeter. The millilambert is of course 1/1000th of the Lambert.

measure light in absolute values. The eye can, however, detect very small differences in the brightness of two adjacent surfaces. At ordinary brightness levels and under the best conditions for observation, that is, no color difference and no dark line apparent between the two evenly illuminated white surfaces, differences as small as about 0.1 to 0.2 per cent in brightness can be detected.

The Receptors of the Eye. Since the change in the sensitivity of the eye with the change in the brightness of the surface observed is to be discussed, something should be said about the eye as a receiver and evaluator of radiation. The eye has two types of receptors of radiation, the cones and the rods. The central (axial) part of the eye—the fovea—covers an area of about one square degree and here the receptors are almost entirely cones. (The sun subtends an angle of about one-half degree at the surface of the earth.) From the center toward the periphery the cones become less in number—the intervening space being filled with rods. Visual impulses from both the cones and rods are transferred to the brain through the optic nerve with characteristic differences in the mode of connection. The cones have, in general, shall we say, private lines to the brain, as well as more diffuse connections, while the rods have multiple connections to a number of nerve fibers less than the number of rods. In consequence the importance of the contribution of the cones to the picture as seen by the brain, for ordinary field brightnesses, is much greater than would result from the relative area covered by the cones and rods. These two receptors differ somewhat in these functions. Besides responding to light intensity, the cones respond to the spectral-quality differences called color, and to the fine geometric details which are designated as acuity. The rods are sensitive to light intensities lower than that for which the cones function well, and are relatively more sensitive for radiation of shorter wavelengths than are the cones. They also respond to larger detail of the image and to sudden changes in the stimulus pattern. The cones are concentrated in that part of the retina best suited for the functions they are to perform, since, like other optical instruments, the eye furnishes the best definition near its own axis of symmetry.

Standards of Light Intensity. Before anything further is said about the eye as the measuring device for light, the method of making the measurements and the standard used will be discussed. The first question is—What characteristic of the light source, in its relation to the eye, is best to choose as the basis of rating different sources? As the eye functions, in evaluating light sources, it is influenced by several characteristics of the source, or by the characteristic of the object illuminated by the source. These might be listed as the color and intensity of the light, and any changes in either of these, the geometrical detail in varying degrees of the object illuminated, and any movement of these objects. Besides some of the physical characteristics of the source itself, such as the total amount of radiation within the visible spectrum, and the spectral distribution of this radiation, there are several characteristics of light and its use with the eye that can be measured. There may be some question about using the word "measurement" here, but at least the characteristics of the source studied, as they affect the eye, can be compared with the effects of like characteristics of

some source selected as the standard. And what is measurement but a comparison with a standard?

Some of the characteristics that might be measured follow. A light source illuminates objects, and the resulting brightness, which is the effect of the illuminated surface on the eye, may be measured and taken as an indication of the value of the light source. This means first selecting the proper surface to be illuminated and then measuring its brightness in terms of that given by a previously selected standard. Again it has been suggested that some visual task such as reading be taken as a criterion for determining the value of light, and an illuminometer for this purpose was suggested and tried out. This might be extended and the visual acuity as measured by some of the standard methods taken as an indication of the relative value of light sources.

Another method that might be used is threshold photometry which has been used for studying the sensitivity of the eye and some other experimental work. This consists of a determination of the instantaneous thresholds, which are the lowest brightnesses of the selected surface that can be seen, under definite conditions of illumination and observation, with the eye initially adapted to a definite field brightness and the thresholds determined before the eye can change. The assumption is made that these instantaneous thresholds are equal. Another method is to use as a criterion the least change in brightness of an illuminated standard screen that one can detect. It is not to be expected that these different methods will give the same relative ratings for various light sources.

About fifty or sixty years ago there was some discussion of these problems and as a result engineers continued to follow the more or less established practice; that is, to rate light sources in terms of their intensity, which was determined by measuring the brightness of a selected white surface illuminated by the source studied.

The Candle. As soon as the decision was made as to the method, a standard source had to be selected. Perhaps because the candle had been used so long as a unit light source, engineers again following established practice adopted it as a standard and gave its name to the unit. Thus other light sources came to be referred to as giving a light output equal to that of a certain number of candles. At least two other flame standards were set up and used as standards—these were the Hefner lamp, burning amyl acetate, and the Vernon-Harcourt lamp, burning pentane. Since it was found that the light output of the candle and the other flame standards depended upon their construction and use, very definite instructions were set down for making and operating these flame standards These served for a time but finally a more definite standard had to be selected which will be discussed later.

Photometers. To measure the brightness of the selected white screen, rather to bring it to the same brightness as the one that is illuminated by the standard source, photometers were developed. These were based upon the ability of the eye to decide when two adjacent surfaces were at the same brightness. To bring these two surfaces to the same brightness, some means must be provided for reducing or increasing the brightness of the screen due to one of the sources

being compared. This is generally done by moving one of the sources to or from the photometric screen, using the inverse square law to reduce the brightness of the screen. The reading taken is thus the distance of the lamp, that is moved, to the photometer screen, which for accurate work should be at least 100 centimeters.

For the most accurate work the method of substitution is used; that is, a comparison source is used permanently on one side of the photometer and the standard and the source being measured used in turn on the other side. This eliminates any differences due to the photometer. Up to about 1888, many such devices were constructed to enable the observer to make comparisons of the two surfaces that were illuminated by the light from the two sources being compared. Then Lummer and Brodhum brought out two new photometers which since then have been the standard types of optical devices for viewing parts of the two sides of a selected white screen, one side of which was illuminated in turn by light from the standard source and the source being investigated and the other side by the comparison source. These optical devices were so constructed that the line of separation of the image of the two parts observed was almost invisible, which enables the eye to detect more easily and more accurately small differences in brightness. Two types of the photometer were introduced, the first having a two-part field which consisted of either the two halves of a circle divided vertically or a central circular field surrounded by a ring. The second type consisted of a circular field divided vertically and the center of each half so constructed that the setting for equal brightness is aided by two contrasting strips. These contrast strips are, in general, less bright than the rest of the two-part fields, and for the final brightness match the two trapezoids are supposed to stand out equally—equal contrast—even for a marked difference in color of the two lights compared. In general it takes special training to use thus this contrast photometric field. As originally made, these photometers had an 8° to 10° field.

The Flicker Photometer. The brightness of the two surfaces can be compared by the use of the flicker photometer. This is a method of presenting to the eye of the observer the two halves of the photometric field in rapid and constant succession and has certain advantages when used to compare light sources of different color. Transitions from one field to another must be made without any spurious variations of light due to the method of changing from one field to the other. Devices have been constructed that do this quite satisfactorily. This alternation of fields can be made absolutely smoothly by a polarization device[2]. With the flicker photometer, balance is indicated by the position of minimum flicker. Even with a marked color difference, such as equating the brightness given by the light from a mercury or sodium arc with that from a tungsten lamp, readings can be made. The flicker due to color differences disappears before the flicker due to the intensity difference and thus the final setting is made at minimum of intensity flicker. The flicker method does not, however, eliminate difficulties due to field size, the part of eye used or the variation with different observers. What it does do, however, is to enable individual observers

to make settings with color difference that seem impossible to make by direct-comparison methods.

Many tests have been made[3] of the relative values obtained by the flicker photometer and the equality-of-brightness photometer with or without the contrast features, and it has been found that for an angle of observation of about 2° and a field brightness of about 2–3 millilamberts, the two methods agree to better than one per cent for color differences such as that between the color of the light from a carbon lamp (T_c = 2080°K) and a vacuum tungsten lamp (T_c = 2400°K). Results also indicate that for these conditions of observation these two methods give very nearly the same results even for comparison of the tungsten standards with the highly colored light sources.

The International Candle. About the time the carbon lamp came into general use, it was found to be more constant than the flame standards against which it was being measured. This had been recognized by several workers but it was Hyde[4] at the National Bureau of Standards, about 1907, who started the work that resulted in the establishment of the "International Candle." To set up this new standard, comparisons were made between a number of selected and well aged carbon lamps and the flame standards, at the different standardization laboratories and then some of the secondary carbon standards, from the National Bureau of Standards, were carried by Hyde to the standardization laboratories of Great Britain, France, and Germany, where they were carefully compared with like secondary carbon lamp standards. The representatives of these laboratories adopted an average of the values of these selected carbon lamps thus calibrated and designated this as the International Candle.

This is an arbitrary standard and one that cannot be reproduced in a standardization laboratory except by comparison with the standards thus set up. This is not much different from the condition for other standards which are maintained by certain models that are set up. In this, however, the value of the standard is apt to change with usage.

The Germans declined to accept the International Candle, keeping the Hefner lamp as their standard of light intensity. The International Candle thus set up has been the basis of all measurements in the countries that adopted it for about the past 35 years.

Accurate standards for the carbon lamp were no more than introduced and found satisfactory than trouble was encountered. This was due to the introduction of the tungsten lamp which operated at a temperature about 300°C higher than the carbon lamp and thus a color difference was introduced.

Candlepower and Color of Light. The International Candle is defined for one quality of light, that is, for a source at a color temperature* of about 2080°K. Now what is the candlepower of a lamp that emits light of a different color? This is a real question. From definition, the candlepower, or luminous intensity, of any source of light is its light intensity measured in terms of the

* The color temperature of a radiator is defined as the temperature at which it is necessary to operate a blackbody so that the emitted light of the blackbody will match in color that of the source studied.

average of these standard carbon lamps with the condition of equality judged by the average eye under established conditions of photometry. It is difficult to set the two selected white surfaces to the same brightness with a color difference, but it can be done. Any color difference, indeed any difference in spectral distribution within the visible spectrum, whether it results in a perceptible color difference or not, will increase the variations of the reading of any one observer from his own mean and also cause systematic difference in the readings of various observers due to physical and physiological difference in their eyes.

Measuring Lights of Different Color. Many different methods[5] and types of photometers were suggested for measuring the intensity of light sources where the output differs in color from that of the standard. Some advocate the use of the Lummer and Brodhun equality-of-brightness or contrast cube and averaging the results of a great many observers, and others advocate the use of the flicker photometer.

A satisfactory method for comparing light outputs of different color is to use the Lummer-Brodhun contrast photometer with a filter of such spectral transmission that as nearly as possible a color match is obtained when the screen is used on one side or the other of the photometer, and then a correction made for the light transmission of the filter. When measuring the light from sources of continuous radiation, a blue filter is generally used which means that the filter must be used on the side of the photometer with the low-temperature source. As readings are ordinarily made the comparison lamp is set to give a color match with the standard and the color-equalizing filter is placed between the photometer screen and the comparison source when measuring the light output of the lamp giving the different color.

At first the transmission of the filter thus used to equate the color difference was measured by using a great number of observers and having readings made with and without the filter in place. This, to be sure, introduces all the difficulties and inaccuracies of heterochromatic photometry, but the measurement of the transmission of the glass can be made in the standardization laboratories[6] where they are better equipped to deal with such problems. By this means, fair values have been obtained for the transmission of this blue glass filter—values probably correct to somewhat better than one per cent, perhaps about 0.5 per cent.

A much better method of determining the transmission τ of the blue glass is by calculation, using the following equation:

$$\tau = \frac{\int J_\lambda K_\lambda \tau_\lambda \, d\lambda}{\int J_\lambda K_\lambda \, d\lambda}$$

where J_λ is the radiant intensity per unit wavelength of the source used, K_λ the luminosity factor of the eye (to be discussed later), and τ_λ the spectral trans-

mission of the filter, all for wavelength λ. The spectral transmission of the filter may be determined with a spectrophotometer or a monochromator with some standard energy-measuring device. By this method, values of the transmission of the glass can be obtained that are accurate to about 0.2 of a per cent if it be assumed that the average luminosity values available represent the facts to that accuracy, as seems to be the case.

The use of filters for equalizing the color difference of the light from sources whose intensities are to be measured assumes a final color match. This is seldom obtained and thus errors are apt to be introduced.

Candlepower Standards for Sources at High Temperatures. To overcome the color difference between the carbon-lamp standards and the new tungsten lamp, the photometrists at the National Bureau of Standards used a blue glass[6] between the carbon-lamp standard and the photometer screen. By the use of this blue glass, tungsten-lamp horizontal-candlepower standards of intensity rated at 1.25 watt per mean horizontal candle were established in terms of the carbon standards. The transmission of the blue glass was measured directly using the regular photometer and a number of observers.

This problem was no more than settled when another change was necessary due to the introduction of the gas-filled tungsten lamps which operated about 400°C higher in temperature than the vacuum tungsten lamps. Thus another correction due to color difference was necessary.

Mean-Spherical-Candlepower or Lumen Standards. The form of the filament of the gas-filled incandescent lamp was changed from that of the vacuum tungsten lamp and not kept the same for all such lamps, so that a constant relation between mean spherical candlepower and mean horizontal candlepower no longer held. At about this same time it was decided to give the output of incandescent lamps in lumens rather than in mean horizontal or mean spherical candlepower, and so the best solution for these difficulties seemed to be to use the Ulbricht sphere and measure the mean spherical output of the incandescent lamp.

It has been shown that the mean spherical candlepower of different lamps can be compared by operating them in turn inside a large sphere painted white on the inside. The relative spherical candlepowers or lumens of the lamps thus operated vary as the brightness of a small piece of opal glass inserted in the surface of the sphere in such a manner that the brightness of its outer surface can be measured from the outside.

At the National Bureau of Standards[7] six 500-watt gas-filled incandescent-lamp standards of spherical candlepower were first set up about 1917. Very elaborate experiments and measurements were made to cover the two steps; i.e., the one due to the difference in color, and the other from mean horizontal to mean spherical candlepower.

The color difference was overcome by the use of a blue filter. Fortunately the same filter that was used for the color difference between the carbon standards and the 1.25-watt-per-candle tungsten lamp was satisfactory for this step (a slightly different transmission, however). The step from mean horizontal candlepower to mean spherical candlepower was determined by an elaborate

set of measurements in various directions and then integrating to obtain the factor giving mean spherical candlepower from the mean horizontal candlepower.

Twelve years later in 1929 the mean spherical candlepower of these 500-watt lamps was rechecked by an entirely new set of measurements[8]. The average value obtained in this check measurement of the six 500-watt gas-filled mean-spherical standards agreed to within about 0.25 per cent with the previous values.

Operating Conditions for Ulbricht Spheres. Practical operating conditions have been worked[9] out for the sphere so that very accurate measurements can be made on the lumen output of different-sized lamps in terms of the spherical standards that have been set up.

An important factor is the paint on the inside of the sphere, since the character of the paint determines the success of the sphere. The paint should have a high reflecting factor, be as nearly white as possible, and have a matte surface, since the operation of the sphere depends upon the paint following Lambert's cosine law* within a few per cent in its reflection of the light from the lamp.

Possible Errors in High-Temperature Lumen Standards. It was discovered that the mean-spherical-candlepower standards that were set up at certain laboratories in Europe did not agree with those set up at the National Bureau of Standards. As a result of this a number of tungsten lamps were measured in this country and in several laboratories in Europe. It was found that certain European laboratories obtained higher lumen values for the lamps at higher color temperatures than were found here, which meant a smaller value of the candle. This difference ranged from about 1 to 2 per cent at the color temperature (2350°K) of the 1.25-watt vacuum tungsten lamp to from about 1 to 6 per cent for the color temperature (2800°K) corresponding to the 115-volt, 500-watt gas-filled standards.

There were three chances for error between the carbon standards and the gas-filled-lamp lumen standard, two due to color difference, and the third due to passing from the mean horizontal intensity to the mean spherical intensity.

International Standardization. In 1928 the International Commission on Illumination (ICI) appointed a committee[10] to make a check of this difference. This committee adopted, as the standard method for making photometric comparisons with such color differences that existed at either of the two steps between the light output of gas-filled tungsten-filament standard lamps and the carbon-filament standards, the use of the regular Lummer-Brodhun photometer and a blue glass filter to equalize the color difference. It is fortunate that the use of the same filters will practically equalize the color difference between carbon-lamp standards and the 1-25 watts-per-mean-horizontal-candle vacuum-tungsten-lamp standards and also for the next step to the 500-watt gas-filled standards of mean spherical candlepower (color temperature about 2800°K). The step from the mean-horizontal standard to the mean-spherical was to be made by careful integration from measurements in different directions.

* A surface that obeys Lambert's cosine law so radiates or reflects light that it has the same brightness from whatever angle observed.

The total transmission of the blue glass filter is to be obtained from its spectral transmission, the color temperature of the comparison source, and the accepted values of the luminosity factor.

Blue glass filters were selected of such transmission that they nearly equalize the color difference between the carbon-filament standard and the 1.25-watt vacuum tungsten standard, and also between the 1.25-watt vacuum tungsten standard and the 120-volt, 500-watt gas-filled-tungsten standard. Samples of this blue glass were sent to the various standardization laboratories and measurements of its spectral transmission were very carefully made, and from this the total transmission was calculated[11].

These glasses were then used in checking the tungsten-lamp standards at a color temperature of about 2350°K and 2800°K. This work was finished at the various laboratories some time in early 1939 and the reports made. It was found at the National Bureau of Standards that the values of the 1.25-watt vacuum tungsten standard as measured in terms of the transmission of the blue glass, which transmission of course depends upon the values of the ICI luminosity factor, was about 1.5 per cent higher (that is, the candle at this color temperature was smaller) than the value previously assigned to it. Likewise the value of the 500-watt gas-filled standard was found to be about 1.9 per cent higher than the value previously assigned to it by the National Bureau of Standards. The values of the standards at 2350°K and 2800°K were in good agreement with like values found in the other standard lamps.

Meanwhile, another standardization was in process.

The Waidner and Burgess Standard of Light Intensity. The International Candle maintained in terms of the light output of the selected carbon lamps represented an important step in advance, even if this method of maintaining the standard is not entirely satisfactory, mainly because there was no way of reproducing this standard with the necessary accuracy.

Some years ago Waidner and Burgess[12] suggested that the brightness of the blackbody at the temperature of freezing platinum be adopted as the standard of luminous intensity. This should give a standard of light intensity that could be reproduced at any time in any laboratory that was willling to do the necessary work. About fifteen years ago this standard was set up at the National Bureau of Standards and very carefully calibrated in terms of the International Candle, as maintained by the carbon-lamp secondary standards that were set up in 1907, by Wensel[13] and his co-workers. To do this they made and used several special blackbodies that could be immersed in the molten platinum. In these tests four different ingots of very pure platinum were used and many determinations made of the temperature of the freezing platinum, and of the brightness of the blackbody at this temperature. Like measurements were also made in some of the other standardization laboratories and a very good check obtained. The average value for the brightness of the blackbody obtained at the standardization laboratories at the temperatures of freezing platinum was found to be 58.84 candles per square centimeter.

The New Candle. It was then decided to take the value of the brightness of

the blackbody at this temperature as 60 new candles per square centimeter and to adopt this as the new standard of light intensity; that is, the "new candle". One reason for setting this brightness at 60 new candles was that this would correct the errors in the values of the standards at high temperatures with less changes. At the same time the above discrepancies in the values of the standards at the color of the 1.25-watt tungsten (2350°K) and at the color of the gas-filled tungsten lamp (2800°K) would be ironed out. Thus it was decided to make the two changes at the same time. This change affecting both the value of the ultimate standard at a color temperature of 2046°K and the values of the standard at the two higher temperatures (2400°K and 2800°K) was to go into effect January 1, 1940, but this could not be done and the change will probably be made soon.

In the last few years photometrists are again having some trouble with color differences due to the necessity of measuring the luminous output of the sodium arc, the high-pressure mercury arc and some gaseous discharge lamps, and the various types of fluorescent lamps, each of which gives light that differs markedly in color from the incandescent lamp.

Where this work had to be done by eye observation, a color filter was selected that gave the best color match possible and readings were made in the regular manner. Much of this difficult work was avoided by the use of physical photometry, but a discussion of such instruments will be delayed until after some more discussion of the eye as a measuring instrument.

Heterochromatic Photometry. In reality this heading should have been placed above the first paragraph discussing the measurements of the light output of vacuum tungsten lamps. It has been reserved to head this paragraph because the color difference now encountered due to the introduction of various high-pressure mercury arc lamps, sodium arc lamps, neon lamps, and the many fluorescent lamps of various colors, is of a different character from that previously encountered. Considerable work has been done on the problem of measuring the light output of these new lamps, but only the results of some measurements made in this laboratory will be given[14].

The light output given by any one of these new lamps can be measured by one of at least four methods. These are: the direct-comparison photometer with or without the use of a filter, the physical photometer, and the flicker photometer. As already mentioned[3], it has been shown that the flicker photometer and the direct-comparison photometer give very approximately the same results for small fields; i.e., about 2°, and a brightness of from 2 to 3 millilamberts.

Seventeen persons at Nela Park that had more or less experience in photometry were selected and made measurements on a number of these new lamps. H. E. Ives[15] has outlined a method of testing the character of the eye of the observer for photometric work. This consists of a measurement of the relative transmissions of a yellow and a blue filter. These filters (solutions) were so selected that their relative transmission was unity for the average eye. The value of the relative transmission obtained by these seventeen selected observers ranged from 0.677 (one observer, the next lowest is 0.905) to 1.113, with an average of 0.992.

The first test was a comparison of the light from a 400-watt high-intensity mercury lamp with that from a tungsten lamp set at a color temperature of 2800°K. Two field sizes were used, the small field being about 2° and the larger 8 to 10°, with a selected blue filter between the tungsten comparison lamp and the screen when measuring this mercury lamp. It was found that with the best filter used, values 3.7 per cent higher were obtained for the light from the mercury lamp when using the small angle of observation, as compared to the results with the larger angle used. The observers making this test found an average ratio for the transmission of Ives' filter of 0.965.

The next test was a comparison with a tungsten standard, by a group of eleven observers who found a transmission ratio of the Ives solutions of .984, of a green fluorescent lamp, a sodium lamp, and a mercury lamp, using with each lamp a filter selected to give as good a color match as possible and the measurements made with both the flicker and direct-comparison photometers, using the small field in both cases. In this test the mean value found for the green fluorescent lamp, using the direct-comparison photometer was 3.3 per cent higher than that found using the flicker photometer. The value for the sodium lamp was 0.9 per cent lower and that for the mercury lamp 0.8 per cent higher for the direct-comparison photometer. For these color differences and this small number of observers this is thought to be a good check.

The difficulty of making photometric balance of the light output of sources of different colors with a direct-comparison photometer has led some to think that such settings were almost impossible to make and were without meaning. This is no more true than it would be to say that an alternating current is never equal to a direct current. Although there are many instruments that will not measure both direct and alternating current, a direct current can, in many ways, be set equal to an alternating current. The same is true in photometering light outputs of different colors. Many observers cannot make photometric matches between two fields that differ markedly in color, as for instance, if one field is illuminated by a sodium lamp and another by a tungsten lamp. However, such work has been done in various laboratories from time to time as the need arose. It must be remembered, of course, that much less accurate readings are obtained when the two fields being compared differ in color.

To show what can be done, ten experienced observers made a comparison between the light from a sodium lamp and a tungsten lamp at a color temperature of 2900°K. The regular contrast Lummer-Brodhun photometer with a field of 8 to 10° and a field brightness of about 4 millilamberts was used. Some of the observers that took part in this experiment had previously made a test of their eyes by measuring the relative transmission of the Ives' solutions. Among these was the one that found the lowest values (0.677) and one that found one of the higher values (1.072) for the relative transmission of these solutions. The relative values obtained for the candlepower of a sodium lamp ranging from 80 to 109, where the one that found the lowest value for the relative transmission of the Ives' solutions obtained the lower value, and the observer with the higher value of the relative transmissions of the Ives' solutions found the value of 109. The average of the group was 100. The most experienced observer showed a spread

of about 2 per cent in the candlepower of the sodium lamp in ten readings in a single series, while the observer with the least experience showed a spread of 28 per cent in ten readings. Some of the other more experienced observers showed a spread of 10 to 12 per cent in ten readings. This test shows at least that such comparisons can be made, but that for any high degree of accuracy in the results a number of selected observers should be used.

Another test[14] of the light output of sources of various colors was made by measuring the spectral distribution of radiation from these various sources, calculating their light output from these measured values and the ICI luminosity factors, and then comparing these results with candlepower values of the same sources measured in terms of tungsten-lamp standards by the flicker photometer with a small field. The results of such a test are shown in Table 1. These results were obtained by twelve of the selected observers. Their average for the

TABLE 1

Measured and Calculated Values of the Candlepowers of a Number of Lamps

LAMP	CANDLEPOWER	
	Measured	Calculated
Tungsten standard*	1415	1408
Mercury H-1	1501	1470
Sodium	1021	967
Neon	337	335
Fluorescent		
Green	125.2	135.0
Pink	49.5	46.9
Blue	44.0	45.0

* Mean from standard lamp (color temperature 2850°K) calibrated at National Bureau of Standards.

relative transmission of the Ives' solutions was 0.985. It is to be noted that good agreement was obtained.

The relative light output of the two strong mercury lines ($\lambda = 5461$) and ($\lambda = 5780$) given by the 400-watt arc were separated by special filters obtained from Corning Glass Works and measured by the flicker photometer by sixteen observers that found a transmission ratio of the Ives' solutions of 0.989. The spectral radiant intensity of each of these lines was measured and from these values and the ICI luminosity factors, the relative light output was calculated. The agreement is shown in Table 2.

The results of these tests show that photometric comparisons between lights markedly different in color are possible, but that some care must be taken in selecting observers, since occasionally an observer may be found that differs markedly from other observers. In this case the observer with a low value for the relative transmission of the Ives'[15] solutions and the observer with one of the higher values for the relative transmission of the Ives' solutions gave values that differ markedly from the average of the group used as shown in Table 3. Even

with a selected and tested group of observers, more than 15 to 20 observers should be used to obtain a reliable average, or some selection of observers should be made.

TABLE 2

Relative Luminous Intensity of the Yellow and the Green Mercury Lines as Measured by a Number of Observers Using a Flicker Photometer

OBSERVER	EYE CONSTANT	OBSERVED LUMINOUS OUTPUT THROUGH THE SCREEN		
	Y/B	Yellow	Green	Y/G
W. E. F.	1.008	447	324	1.379
A. L. S.	.964	427	319	1.340
A. H. T.	1.055	443	312	1.420
G. K.	1.047	446	314	1.423
C. F. K.	.677	451	425	1.061
N. F.	1.072	454	316	1.438
J. F. R.	1.001	472	334	1.410
M. G.	.998	431	321	1.340
O. U.	1.004	450	331	1.360
W. J. M.	.997	435	316	1.377
G. R. B.	1.113	426	280	1.521
V. J.	.951	439	348	1.263
P. D. C.	.908	428	326	1.310
E. Q. A.	.967	421	310	1.356
B. T. B.	1.004	449	337	1.357
R. W. U.	1.058	420	301	1.393
W. E. F.	1.009	440	316	1.393
A. L. S.	.964	420	313	1.341
Mean	.989			1.360

TABLE 3

Values of candlepower of some colored light sources as measured by the two observers whose eyes were at about the extreme of red and blue sensitivity. The average value found by the group was in each case taken as 100

LAMP	CANDLEPOWER RELATION TO GROUP	
	C. F. K.*	N. F.†
Neon	56	124
Green fluorescent	134	87
Blue fluorescent	133	94
Pink fluorescent	80	112
Mercury arc	115	99
Sodium arc	91	111

* Relative transmission of the Ives' solution 0.677.

† Relative transmission of the Ives' solution 1.072.

Physical Photometry. Due to the many difficulties in visual photometry, and because results obtained when large color difficulties are encountered depend upon

a particular observer whose readings may vary from day to day due to eye fatigue, etc., there has been a desire for a long time to set up some sort of physical photometer to make these measurements.

Such a physical photometer requires an energy-measuring device that will weigh radiation of different wavelengths the same as the average eye. To make such a device is difficult. Not only must the device selected weigh the radiation in the proper manner, but the final output (temperature change, resistance change, or current) must be of such magnitude that it can be measured, and, in addition, the apparatus must be sufficiently rugged to stand up under ordinary use. One of the methods tried was a special photoelectric tube with a filter selected so that the combination would have as nearly as possible the proper spectral sensitivity. This worked so satisfactorily that for some time now practically all the measurements of the light output of lamps made in the laboratories of the lamp factories in this country have been made with photoelectric-tube photometers attached to Ulbricht spheres. By the use of this type of physical photometer, three very great advantages are obtained for the industrial laboratories. First, the measurement of the output of the lamps does not depend upon a selected group of trained observers; second, an increased accuracy in the relative measurements for any one type of lamp; and third, increased speed of operation. With this limited physical photometer an operator at the sphere can compare any one type of incandescent lamp with the proper standard as accurately as, or in many instances more accurately than, was possible in the standardization laboratories by eye observation.

The photoelectric-tube photometer as used today will measure the light output of tungsten lamps at various color temperatures with an error of about one per cent for the range of color temperature from about 2700°K to 3200°K. Even this error is eliminated in the lamp laboratories because standards for tungsten lamps of different color temperatures are set up in the standardization laboratories. The photoelectric-tube photometer is now used to measure light intensities of the many sources giving light of various colors, such as the new mercury lamps, the sodium lamps, and some of the new fluorescent lamps, using a factor for each lamp to correct for the difference between the relative spectral response of cell and the eye. These factors are determined from the spectral characteristics of the phototube and its filter, of the sphere paint, and of the various lamps.

A New Measuring Device for Photometry. The dry-disk (barrier-layer) photocell[16] is a very convenient device for the measurement of light output. The material used on the disk is of such a nature that a current is generated when light falls upon it. Thus, with no additional source of power a current is given when the disk is connected in a circuit containing an ammeter of the proper range. This current, under proper conditions, is proportional to the light intensity.

This device is so simple and so easy to use that it is the basis[17] of a small portable illumination-measuring instrument. This disk can be so made that its spectral sensitivity is very nearly the same as that of the average eye. In addition, a filter may be selected that makes its response for measuring light

almost exactly the same as that of the eye. In general this device is used without any filter, and a factor is used when the light output of sources of various color are measured.

The Eye as the Evaluator of Radiation. Many studies[18] of the eye as the evaluator of radiation have been made and many of the characteristics of the eye determined. The eye is a selective evaluator of radiation; that is, it does not rate radiation of all wavelengths alike. Indeed, for the greater part of the extensive radiant-energy spectrum, it gives no response at all. Measurements have been made of the ability of the eye to detect and use the radiation for a range of wavelengths from 0.3 μ to about 0.9 μ, as measured by the relative brightness of two adjacent white surfaces and by the instantaneous thresholds. A very small response is obtained for radiation at these limits and the response increases towards the center, the mazimum for the central part, for the light-adapted eye, coming at about 0.56 μ. Beyond wavelengths of about 0.40 μ in the blue and 0.75 μ in the red part of the spectrum, the values of the responses are almost impossible to measure except with the eyes dark adapted.

Up to about 20 years ago many measurements were made of the relative amounts of radiation required to produce the same brightness in various parts of the visible spectrum. The reciprocals of these relative amounts of energy necessary to produce the same brightness for wavelength intervals are called the luminosity factors. To get consistent results when measuring these factors, it was found necessary to use very definite conditions of observation. One set of consistent values—the photopic values—were obtained if the angle of observation were kept small, i.e., about 2° to 3°, and the brightness level of the field kept in the neighborhood of 2 to 3 millilamberts or higher. Later it was shown that if the field brightness were kept at or above 0.5 millilambert, consistent results could be obtained for a diametrally divided, directly viewed field of the order of 2 to 3°. Experiment has shown that the luminosity values obtained depend both upon the part of the eye studied and upon the field brightness to which the eye has become adapted. Thus it is now a commonplace of visual psychology that the sensitivity of the eye varies for various parts of the retina and for various levels of field brightness. The magnitude of the sensitivity of the eye changes continuously and inversely with changes in the field brightness to which it is adapted, and for some parts of the retina, the shape of the luminosity curve changes for a range of field brightness from about 0.5 millilambert down to about 10^{-5} millilambert.

The ICI Luminosity Factors. In 1923 Gibson and Tyndall[18] of the National Bureau of Standards made a determination of the luminosity of the average eye under very carefully controlled conditions. They used about a 2 to 3° field and a field brightness of about 2 millilamberts. After careful study of previous results, they made an average of their results and some of the previous measurements and gave luminosity factors for the wavelength range from 0.4 μ to 0.76 μ. Their average values were adopted by the IES[19] (Illuminating Engineering Society) in 1923 and by the ICI[20] in 1924 as standard luminosity factors for use in photometry. These final values are given in the second column of Table 4.

Luminosity Factors for Low Brightness. Several determinations[21] have been

TABLE 4

Relative luminosity data for various field brightnesses (as logarithms)

WAVE-LENGTH	ICI	−0.5	−1.0	−1.5	−2.0	−2.5	−3.0	−3.5	−4.0	−4.187*	−4.50	−5.00
mμ												
350									.0002	.000265	.0003	.0003
360							.0003	.0004	.0007	.00073	.0008	.0008
370					.0002	.0005	.0009	.0013	.0018	.0019	.0020	.0022
380	.00004	.0000	.0001	.0002	.0008	.0015	.0025	.0034	.0045	.0048	.0051	.0055
390	.00012	.0001	.0002	.0008	.0022	.0040	.0063	.0083	.0104	.0112	.0119	.0127
400	.0004	.0004	.0008	.0022	.0059	.0098	.0147	.0185	.0228	.0243	.0253	.0270
410	.0012	.0014	.0023	.0062	.0140	.0227	.0305	.0370	.0452	.0485	.0500	.0530
420	.0040	.0044	.0069	.0152	.0280	.0427	.0580	.0690	.0820	.087	.0900	.0950
430	.0116	.0121	.0165	.0292	.0505	.0755	.101	.118	.138	.145	.149	.157
440	.023	.0240	.0300	.0496	.0850	.123	.160	.183	.216	.225	.230	.239
450	.038	.0395	.0490	.0810	.136	.187	.237	.268	.310	.321	.326	.339
460	.060	.0627	.0775	.127	.202	.277	.339	.376	.423	.434	.441	.455
470	.091	.0960	.118	.191	.301	.394	.467	.510	.551	.560	.568	.576
480	.139	.146	.180	.288	.432	.540	.604	.649	.685	.695	.702	.714
490	.208	.220	.274	.426	.592	.688	.734	.782	.814	.827	.830	.842
500	.323	.340	.416	.603	.744	.826	.864	.902	.930	.932	.941	.948
510	.503	.524	.617	.766	.876	.935	.962	.977	.992	.997	.997	.999
520	.710	.726	.792	.894	.965	.992	.999	.988	.974	.963	.960	.953
530	.862	.872	.910	.972	1.000	.982	.951	.924	.883	.871	.862	.848
540	.954	.959	.979	1.000	.969	.909	.842	.796	.744	.734	.715	.697
550	.995	.997	1.000	.971	.886	.785	.698	.642	.583	.555	.552	.531
560	.995	.992	.973	.898	.760	.640	.543	.478	.419	.390	.388	.365
570	.952	.944	.907	.782	.617	.485	.384	.330	.281	.263	.260	.243
580	.870	.860	.802	.648	.468	.340	.259	.218	.182	.167	.164	.155
590	.757	.742	.673	.509	.333	.227	.166	.137	.112	.102	.101	.0945
600	.631	.616	.544	.374	.224	.145	.101	.0830	.0670	.0613	.060	.0560
610	.503	.490	.416	.257	.142	.0870	.0600	.0488	.0388	.0366	.0348	.0324
620	.381	.366	.296	.168	.0845	.0504	.0344	.0280	.0225	.0212	.0202	.0188
630	.265	.250	.197	.102	.0480	.0282	.0194	.0156	.0127	.0118	.0114	.0105
640	.175	.162	.122	.0590	.0270	.0146	.0107	.0085	.0070	.0653	.0062	.0058
650	.107	.0990	.0710	.0327	.0147	.0084	.0058	.0046	.0037	.00353	.0034	.0032
660	.061	.0560	.0390	.0174	.0078	.0045	.0031	.0025	.0020	.00189	.0018	.0017
670	.032	.0303	.0206	.0090	.0041	.0024	.0017	.0013	.0011	.00098	.0010	.0009
680	.017	.0153	.0103	.0046	.0022	.0014	.0009	.0007	.0006	.00050	.0005	.0005
690	.0082	.0076	.0052	.0024	.0011	.0007	.0004	.0003	.0003	.00025	.0002	.0002
700	.0041	.0038	.0026	.0012	.0006	.0003	.0002	.0002	.0001	.00013	.0001	.0001
710	.0021	.0019	.0014	.0006	.0003	.0002	.0001					
720	.00105	.0010	.0007	.0003	.0001							
730	.00052	.0005	.0003	.0001								
740	.00025	.0002	.0002									
750	.00012	.0001										
760	.00006											
770	.00003											

* Average of Weaver and Hecht's values.

made by various observers of the luminosity factors for the eye adapted to low brightness—the scotopic values. The values for the low-brightness curve ($6.5 \cdot 10^{-5}$ footlambert) shown in Column 11, Table 4, are average of the measurements of Hecht and Williams[21] and of Weaver[21].

Later Koomen[22] at the University of Rochester extended the low-brightness calibration curve toward both the blue and the red ends of the spectrum. Toward the blue Koomen extended the values to almost 0.3 micron and toward the red to about 0.8 micron. Goodeve[21], using a threshold method, has extended the curve toward the red end of the spectrum to about 0.9 micron. Hecht and Koomen used a brightness-match method and rather large areas for their fields. Koomen used a 13° circle divided by a vertical line. Hecht used a 22° field also centrally divided. Weaver used a 2.5° central spot surrounded by a 7° ring. Later he divided the spot so that he had the central part separated into about three equal widths with the central one-third illuminated the same as the outer ring.

Goodeve used a small centrally located field that was very narrow (about 0.3°) and about 3° high. However, this does not make much difference in the result for the red end in the spectrum, since it has been shown that here there is very little difference in sensitivity between the center of the eye and the area removed from the center.

Wald[23] at Harvard University has shown by experiment that the shape of the luminosity curve for the fovea does not change with the field intensity down to about threshold and that it is practically the same as the ICI curve which is for a larger central area (2 to 3°) and higher levels of illumination. The only difference is that Wald found a hump on the curve for the blue part of the spectrum. Whether this hump would be found on the ICI curve, if it were more carefully determined in this part of the spectrum, one cannot tell, but Wald's analysis and data seem to indicate that it would be. The values of the luminosity factors obtained by Koomen and by Goodeve for the ends of the visible spectrum, or probably one should say of their extensions of the visible spectrum, have been used to extend the luminosity curve for low field brightnesses.

The ICI luminosity curve, which was obtained with a 2° to 3° field and an effective field brightness of the order of one millilambert, agrees well in shape with like values obtained for a central area 1° in diameter for the completely dark-adapted eye, with some reservations as to agreement in the extreme blue end of the spectrum. Similarly, the luminosity curves measured for relatively large areas of the retina and for the dark-adapted eye agree so well with the absorption curve for the visual purple (with the quantum correction) that they may be regarded as the luminosity factors for the rods, with some reservations as to the agreement in the extreme red and blue ends of the spectrum. Nevertheless a luminosity curve determined for a retinal area that contains both cones and rods cannot represent the luminosity curve for either cones or rods, since the action of the cones cannot be completely eliminated by lowering the field brightness, nor the action of the rods completely eliminated by raising the field brightness.

For this kind of work, indeed for almost any type of photometric work, the pattern as well as the size of the field is important. This is well illlustrated by the case of the Lummer-Brodhun contrast photometer field. Using this photometer field, some observers make their settings using the entire field, and thus are aided by the contrast of the two trapezoids, while other observers insist on making the brightness match using only the two central strips. The pattern of the field is particularly important in measurements made in the range of brightness in which marked changes occur in the qualitative characteristic of the luminosity function (the Purkinje range), since these changes vary for different parts of the eye, and one cannot always be sure just how different observers make their settings with fields of various patterns.

The time allowed for making observations also has a significant effect. For the dark-adapted eye the luminosity curve for a 1° field centrally located and for a like area for a part of the retina some degrees out from the center may cross

TABLE 5

Relative luminosity factors for the fovea for long wavelengths

WAVELENGTH	LUMINOSITY FACTORS*
0.60	6.31×10^{-1}
0.65	1.07×10^{-1}
0.70	4.1×10^{-3}
0.75	1.2×10^{-4}
0.80	4.6×10^{-6}
0.85	2.6×10^{-7}
0.90	2.0×10^{-8}
0.95	2.0×10^{-9}
1.00	2.6×10^{-10}
1.15	1.6×10^{-12}

* Maximum unity.

somewhere between 0.6 μ and 0.7 μ, depending upon the conditions of observation. The use of very small areas and short time for observation will raise the threshold throughout the spectrum, and more so toward the peripherial retina, and thus tend to push the crossing point toward shorter wavelengths. For a 1° field and long time for observation—one second or more—the values for the extra-foveal area are generally found to be higher than those for the fovea. The age of the observers has some effect on the final results, particularly at the blue end of the spectrum where some younger eyes seem to be more sensitive than older eyes.

Lately there has been need for luminosity factors for very low brightness and for very long wavelengths. Such relative values were obtained for the fovea by extrapolating the ICI factors using Goodeve's experimenal results. This observer showed that log K_λ plotted against $1/\lambda$ was linear for these very long wavelengths. The values thus obtained and used are shown in Table 5. The relative values of the luminosity factors for low brightness and for a central field of about 6° are obtained with sufficient accuracy for the purpose by ex-

trapolating one of the sets of factors for low brightness (Table 4) using Koomen's and Goodeve's data. Experiment has shown that the values given in Table 5 can be used as an extrapolation for the 6° central vision for very low field brightness and unity maximum if they are divided by 40.

Eye Sensitivity at Low Brightness. It is well known that the sensitivity of the eye increases when the field to which it is exposed is reduced in brightness. This change in sensitivity is different for different parts of the retina; thus to get consistent results a definite part of the retina must be studied.

Suppose that a 3° to 5° centrally located part of the eye be considered. This includes the part of the eye that was used in the determination of the ICI luminosity curve and is within the range of the areas used for several determinations of the scotopic luminosity curve. Experiments have shown that for a field brightness of about 0.5 millilambert and higher, while there is a marked decrease in the absolute value of sensitivity for an increase in the field brightness, there is but little, if any, change in the shape of the luminosity curve. Also, for levels of field brightness from about 10^{-5} millilambert down to the threshold value, where again there is a marked increase in the absolute value of the sensitivity for a reduction in field brightness, there is but little, if any, change in the shape of the luminosity curve. Between these two field brightness levels—0.5 to 10^{-5} millilambert—the change in the eye sensitivity is one both of character, (i.e., shape of curve) and magnitude. The luminosity for any field brightness within this range is represented by a curve somewhere between the photopic and scotopic curves. The change in the shape of the luminosity curve is shown by comparison of the photopic curve—the one for the higher field brightness—and the scotopic curve—the one for lower field brightness.

As ordinarily plotted, Figure 1, the luminosity curves, both for high-level brightness, the photopic curve, and the one for low-level brightness, the scotopic curve, are each set with a maximum of unity. This has led some to think that the eye increases markedly in sensitivity for blue light and decreases in sensitivity for red light, as the brightness is reduced to low values. The eye does increase in sensitivity for low-level brightness for a blue field, but it does not decrease in sensitivity for red light of a low-level brightness; rather it increases in sensitivity, but much less than for blue light. The sensitivity of the eye increases for all wavelengths as the field brightness is reduced. The fact that the increase is much greater for the blue end of the spectrum is what has been called the Purkinje effect.

In this paper it was decided to use the best available data and plot these curves so as to show both the magnitude and the wavelength distribution of the change in the eye sensitivity, both of which depend, of course, upon the part of the eye which is used in the test.

Weaver[24] has given data that show how the wavelength of maximum luminosity changes with the brightness of the field observed. These data have been used by Jones[25] to interpolate values for the luminosity factors for different wavelengths, and for the eye adapted to several different levels of field brightness, between the ICI curve and the curve for low field brightnesses, and has extended these values

to a field brightness of about 10^{-5} millilambert (Table 4). The values for the luminosity factors for various states of dark adaptation, as thus obtained by Jones, are shown in Table 4. Weaver's values for the variation of the wavelength of maximum sensitivity of the eye with dark adaptation shows but little change for dark adaptation below that corresponding to a field of 10^{-5} millilambert. Other experimental data also show that the shape of the luminosity curves does not change for field brightness below that of 10^{-5} millilambert, but it must be remembered that even at these brightnesses it depends upon the part of the retina used. The values of the luminosity factors given in Table 4 for various field brightness can only be taken as tentative. It is hoped that some experimenter in this field will check some of these values in the near future.

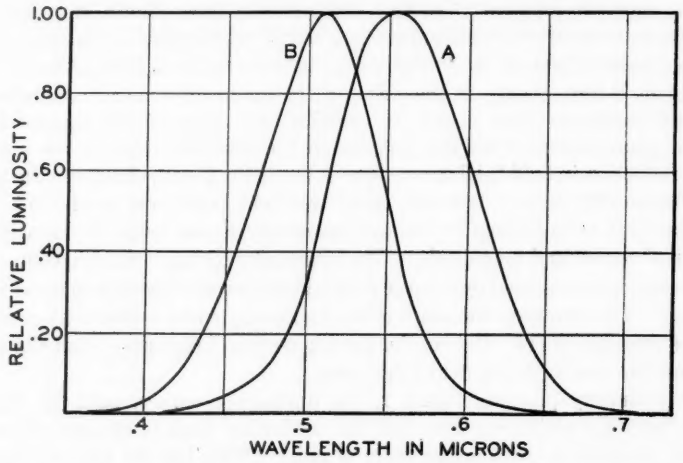

FIG. 1. Relative luminosity curves for ordinary brightness (A—the photopic curve) and for low brightness (B—the scotopic curve).

The next question was to find a method and data for determining the relative magnitude of the eye sensitivity for different states of adaptation. One method of doing this to assume that the instantaneous thresholds, for the eye adapted to different levels of field brightnesses, are all equal as seen by the eye. Thus the change in sensitivity of the eye between the adaptation to two field brightnesses is given by the relative values of the instantaneous threshold for these two brightnesses. This is measured for a particular radiation by the amount n by which it is found necessary to reduce mechanically the energy intensity of the instanteous threshold corresponding to the higher field brightness to reach the threshold for the lower brightness. If J is the intensity of the radiation necessary to use to give the instantaneous threshold for the eye adapted to a field brightness of, say one millilambert, and if n is the factor by which this radiation has to be reduced mechanically to give the threshold for a lower level of field brightness, then n

represents the absolute change in adapting conditions of the eye for this particular type of radiation. That is, the eye is said to increase in sensitivity by this factor n for this change in field brightness for this particular radiation.

Blanchard[26] gives some data on the various characteristics of the eye, including the instantaneous thresholds for a wide range of initial field brightnesses for white and various colored light. The white light used was obtained from a Nernst glower at a color temperature of 2680°K, the light source used in his work, and the red light was obtained by passing this radiation through a red filter that has about zero transmission at 0.6 μ, 45 per cent at 0.62 μ, and 82 per cent for 0.64 μ and longer wavelengths.

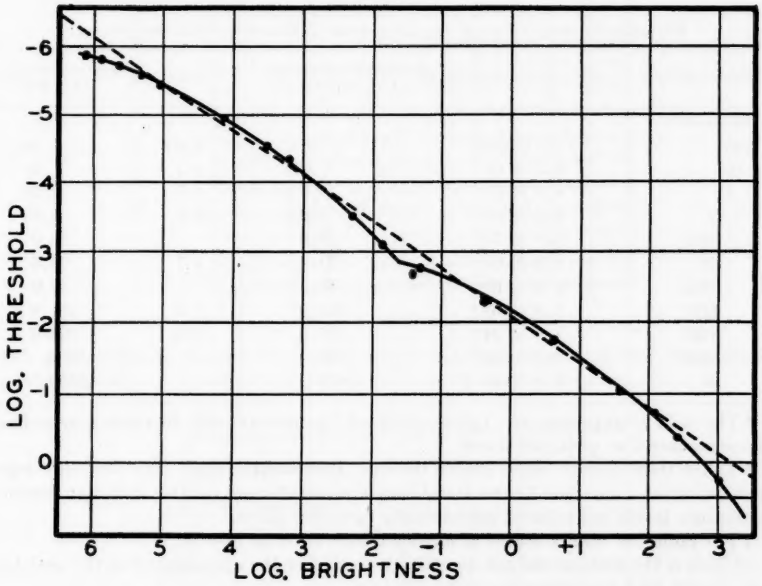

FIG. 2. Minimum thresholds for various field brightnesses

The thresholds given are for both eyes and for a central field of about 5° to 7°. The values of the field brightness and the thresholds were obtained by reducing mechanically brightnesses that were measured at ordinary photometric levels. If these data be plotted, log T (the thresholds) against log B (the corresponding field brightness), an irregular curve results (Figure 2). If the best straight line be drawn through these points and the change in eye sensitivity for these differences in field brightnesses calculated from the values of instantaneous threshold obtained from the straight lines, the values given in Table 6 are found.

The Minimum Threshold. The value for the minimum threshold used was taken from Taylor's[27] work. This value was determined by using both eyes

and a central field of about 6°. The minimum threshold used was obtained by extrapolation from the curve of log T plotted against 1/t (t = the time). Taylor's value for the minmum threshold was obtained using a source at a color temperature of about 2850°K. From the curves shown in Figure 4, this will give a threshold about 10 per cent higher than would have been obtained from a source at the same color temperature as the one Blanchard used. This gives a value of $1.8 \cdot 10^{-7}$ millilambert for the minimum threshold for white light which is reached in somewhat over two hours' dark adaptation. Again this brightness was obtained by mechanically reducing brightness values that were measured at near the photopic level. This value is lower than the average of other data

TABLE 6

Blanchard's data relating instantaneous threshold to field brightness

FIELD BRIGHTNESS*	INSTANTANEOUS THRESHOLD†	RELATIVE SENSITIVITY‡ (n)	RATIO††	RELATIVE VALUE OF MAXIMUM
millilamberts				
100.	1.9×10^{-1}	.047	4.6	.047
10.	4.2×10^{-2}	.021	4.7	.21
1.	8.9×10^{-3}	1.0	4.7	1.00
.1	1.9×10^{-3}	4.67	4.6	4.95
.032	8.9×10^{-4}	10.0		12.0
.01	4.2×10^{-4}	21.4	4.7	29.5
.0032	1.9×10^{-4}	46.7		70.0
.001	8.9×10^{-5}	100.0	4.7	161.0
.0001	1.9×10^{-5}	467.0	4.6	822.0
.00001	4.2×10^{-6}	2140.		3900.
.0	1.8×10^{-7}§	48600.		88500.

* The field brightnesses are values obtained by mechanically increasing or reducing values measured at photopic levels.

† Taken from smooth curve drawn through Blanchard's data. The unit will depend upon definition. As these figures stand they are brightnesses for this radiation measured at photopic levels and reduced mechanically to values given.

‡ For radiation from a source at a color temperature of 2680°K.

†† This is the ratio of the eye sensitivity to that of the eye adapted to the next lower (one tenth) field brightness for this radiation.

§ Minimum threshold from Taylor's value.

given and, although it represents the observations of but two observers, it is consistent with itself.

Luckiesh and Taylor[28] have made an extensive study of dark adaptation for a number of observers and for variously colored lights and they say: "It is commonly assumed that the eyes are completely dark adapted at the end of thirty minutes, but this is not the case. However, the gain in sensitivity after thirty minutes may be of minor importance from a practical standpoint." Their data show this to be the case for radiations of all wavelengths tested, except possibly for $\lambda = 7000$A°.

Taylor's[27] data for dark adaptation for white light show the minimum perceptible threshold to be $4.8 \cdot 10^{-7}$ millilambert for thirty minutes dark adaptation

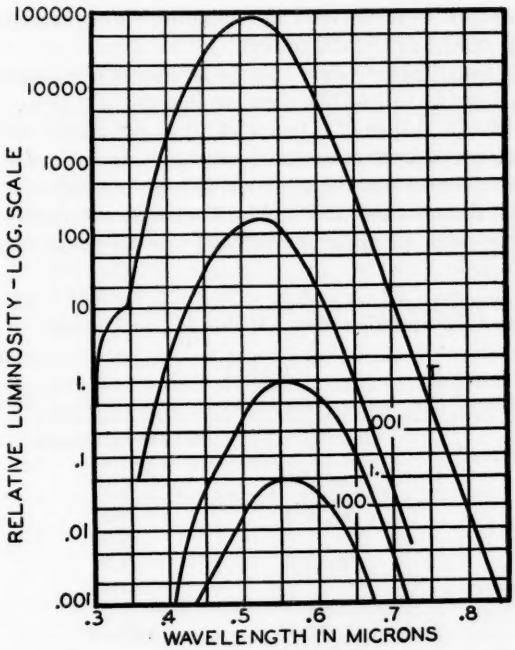

FIG. 3. Relative luminosity curves for the eye adapted to several field brightnesses; i.e., 100 millilamberts; 1 millilambert; .001 millilambert, and for the threshold.

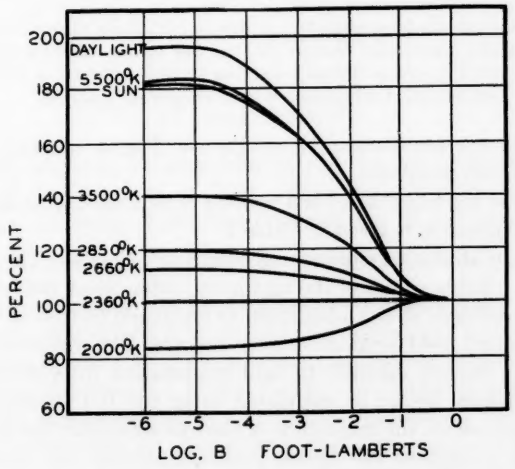

FIG. 4. Relative values of brightness at various field brightnesses and for various color temperatures as compared with a source at a color temperature of 2360°K.

and $2.9 \cdot 10^{-7}$ millilambert for sixty-five minutes. The extrapolated value from the data comes out $1.8 \cdot 10^{-7}$ millilambert.

Blanchard's data (Table 6) show that for a range of field brightnesses from 100 millilamberts down to 10^{-5} millilambert, an increase of a factor of 10 in the field brightness, rather a change of a factor of 10 in the energy intensity that produces the higher field brightness values, causes a decrease of a factor of about 4.7 in the sensitivity of the eye as above defined. If the values from the best curve through Blanchard's[26] thresholds, Figure 2, are used to calculate eye sensitivity, this factor 4.7 might be changed at some points by about ± 15 per cent.

Blanchard also gives ΔB for various values of B for field brightnesses from one millilambert to $4 \cdot 10^{-5}$ millilambert. If this ΔB, with respect to B, be taken as a

TABLE 7

Brightness of a number of natural objects under different illumination*

OBJECTS STUDIED	ILLUMINATION (in footcandles)		
	Sun 10000.	Moon 0.04	Starlight 0.0002
Trees	60.–325.	.0020	.000010
Surface of lake		.0002	.000010
Grass	60.–700.	.0030	.000015
Concrete highway		.0080	.000030
Brick road	1000.		
Sky	900.	.00012–.01	.00015
Clouds	3000–10000		

* These brightnesses were given by Taylor in footlamberts for the illumination in footcandles given in this table. They may equally well be taken in millilamberts for the slightly different illuminations in meter candles.

An illumination of one footcandle is that due to one candle at one foot; an illumination of one meter candle (also called one lux) is that due to one candle at one meter. Under these illuminations a perfectly diffuse reflecting surface will have a brightness of respectively one footlambert and .1 millilambert (also equals one apostilb).

measure of the eye sensitivity, the results would agree qualitatively with those obtained from the threshold.

For reference, the brightness[29] of a number of natural objects under three types of natural illumination is given in Table 7.

Calculation of Maximum Ordinates of Luminosity Curves. The method used to calculate the relative values of the maximum ordinates of the luminosity curves for various conditions of eye adaptation as compared to that of the eye adapted to some standard field brightness is as follows: The values of instantaneous thresholds for the eye adapted to field brightnesses from about 0.5 to 1 millilambert or higher are to be calculated using the ICI luminosity values $K_{p\lambda}$, corrected of course for the magnitude of the eye sensitivity for these field brightnesses. This is because the instantaneous thresholds are taken immediately after the adapting field, which was above 0.5 millilambert, was turned off, and thus the eye has no time to change its condition of adaptation. The same is

true for each threshold; that is, the luminosity values to use are those for the eyes adapted to the corresponding initial field brightnesses. This light, the threshold for this condition of adaptation, if the field brightness is above 0.5 millilambert, say, one millilambert, is $L_1 = \int J_\lambda K'_{p\lambda}\, d\lambda$ where J_λ is the value of the spectral energy intensity for the instanteous threshold for this adapting brightness, $K'_{p\lambda}$ the absolute value of $K_{p\lambda}$, the ICI luminosity factor for the brightness at which the eye is initially adapted. Likewise the minimum threshold L_2 (for dark-adapted eye) is to be calculated using the luminosity factors $K'_{s\lambda}$, corresponding to the state of adaptation of the eye. This light is $L_2 = \int \frac{J_\lambda}{n} \cdot K'_{s\lambda}\, d\lambda$ where n is the amount that J_λ has to be reduced mechanically to reach this minimum threshold. These two values are both threshold and according to the assumptions they are equal as rated by the eye. Thus consider the case for the instantaneous threshold corresponding to a field brightness of one millilambert equated to the minimum threshold:

$$\int J_\lambda K'_{p\lambda}\, d\lambda = \int \frac{J_\lambda}{n} K'_{s\lambda}\, d\lambda$$

or

$$C_p \int J_\lambda K_{p\lambda}\, d\lambda = \frac{C_s}{n} \int J_\lambda K_{s\lambda}\, d\lambda$$

where

$$CK = K'$$

thus

$$\frac{C_s}{C_p} = n \cdot \frac{\int J_\lambda K_{p\lambda}\, d\lambda}{\int J_\lambda K_{s\lambda}\, d\lambda}$$

n is the change (increase) in sensitivity of the eye from the high to the low adaptation level for this kind of light. Since the color temperature of the source is known, the value of the two integrals can be calculated by step-by-step integration of the products indicated, and thus the value of the ratio $\frac{C_s}{C_p}$ of the maximum ordinate of this low-brightness luminosity curve to that of the selected photopic curve can be determined from the value of n given in Table 6. In the same manner the ratio of the maximum ordinate of the luminosity curve for any other state of adaptation to that for the eye adapted to a field brightness of 1 millilambert can be calculated. If the ICI luminosity curve for a field brightness of 1 millilambert be plotted with the maximum equal to unity, then the minimum-threshold luminosity curve on the same relative basis must be plotted with its maximum ordinate equal to C_s/C_p, which equals from the data

used about 88500—the relative absolute value for the minimum-threshold luminosity factor to that for the photopic curve set at unity. This means that the eye has increased in sensitivity for this radiation by a factor of 48,600 due to a change in the field brightness to which it was adapted from 1 millilambert to $1.8 \cdot 10^{-7}$ millilambert.

The relation between the maximum ordinate of the luminosity curve for any other field brightness and that for, say, a field brightness of 1 millilambert is to be obtained from the data in Table 2 and like calculations using the corresponding luminosity values from Table 1. In Figure 3 are shown four such relative luminosity curves.

The photopic and scotopic luminosity curves are different in shape when plotted at unit maximum (Figure 1), the scotopic curve being more narrow which makes the area under this curve about 13 percent less than that under the photopic curve. Suppose it were possible to compare in brightness, by eye observation, a surface at a brightness of 1 millilambert with a like surface having the energy falling upon it reduced by a factor of 10^5, making the measurements in such a manner that the surface of the high brightness is viewed with the light-adapted eye and the other surface with the dark-adapted eye. This would be very difficult to do but some such data have been obtained[30] by using both eyes; the one light adapted viewing the surface at higher brightness, and the other surface viewed with the other eye which is dark adapted. Since the luminosity factors are known for the light-adapted and for the dark-adapted eye, these data, together with such data as that given in Figure 3 and Table 5, can be used to calculate these relative brightnesses.

It will be found, either by measurement or by calculation, that if the energy falling upon a white surface initially at a brightness of 1 millilambert is reduced by a factor of 10^5 and the resulting change in brightness determined for the eye adapted to this low brightness, its brightness will be altered due to four causes: the reduction of the energy falling upon it, the fact that the scotopic curve is more narrow than the photopic curve, the energy distribution relative to the location of the photopic and scotopic maxima, and due to the increase in absolute sensitivity of the eye. The part of this change that is due to the spectral characteristics can be calculated from the data in Table 4 and the spectral characteristics of the radiation used.

For a source at a color temperature of 2680°K, such as Blanchard used, the brightness is thus further reduced by a factor of 1.82; for a source of uniform spectral distribution of radiation this factor is 1.13; and for a source at a color temperature of 2360°K the brightness is reduced by a factor of 2.06. If monochromatic radiation is used, almost any factor greater or less than unity can result. Suppose monochromatic radiation at $\lambda = .65\mu$ be used. From the data Table 4 this factor becomes 33.5. On the other hand, for monochromatic radiation for $\lambda = 0.45\mu$, the brightness is not reduced at all but is increased by a factor of about 9. The question is, how much the brightness of this surface seems to the eye to be reduced taking into consideration the three factors: the mechanical reduction, the relative area under the two distribution curves and the increase in sensitivity of the eye due to its being dark adapted.

For the case described by the data in Table 6, that is, a white surface illuminated by a source at a color temperature of 2680°K, the reduction in brightness, due to the characteristics of the energy used, is 1.82. Thus the total reduction for a mechanical reduction of 10^5 amounts to $1.82 \cdot 10^5$. Since the sensitivity of the eye is increased by a factor of 2140, due to this dark adaptation and this radiation, it would seem to the eye that the brightness of the white surface had been reduced only by a factor of 46.8. These data are for the change in the sensitivity of the eye as a whole. Calculations have been made by others[31] of the sensitivity of the retina making allowance for change in pupil area with or without corrections for the transmission of the ocular media.

Standard for Low Brightness. Since the spectral characteristics of the eye as a light-measuring instrument change when the level of the field brightness to which it is adapted is reduced much below about 0.5 millilambert, the eye will not give the same relative values of the light output for sources of different spectral characteristics at high and at low field brightnesses. For this reason photometry at very low brightnesses becomes extremely interesting and in this field some care must be exercised. Thus it is necessary to pay very careful attention to any standard of intensity that one uses at these low levels of illumination.

All of these peculiar reactions of the eye make for a lot of trouble in measurements. Practically all the data thus far used in this paper for very low brightnesses, even down to the minumum threshold, were obtained by mechanically reducing a brightness of such magnitude that the light output could have been and probably was measured at ordinary photometric levels. Thus, for a number of cases when a brightness of, say, 10^{-5} millilambert has been given, it means that the radiation from a source giving a brightness of 1 millilambert was reduced by a factor of 10^5.

Since the sensitivity of the eye changes in character as well as in magnitude as the field brightness is reduced below about 0.5 millilambert, two sources of different color that give an equal amount of light at the high field brightness may differ markedly in the amount of light they give if they are both reduced mechanically the same amount and then evaluated with the dark-adapted eye. From what has been said, the source that has more radiation in the blue part of the spectrum will give more light flux at the low field brightness. This is not the fault of the source or the way radiant energy behaves at low brightness levels, but is due wholly to the change in the spectral sensitivity of the eye.

Dr. Jones[32] calculated the change in brightness for sources at several color temperatures that the eye would indicate if their radiant energy were mechanically reduced and these compared with the adopted standard given by a source at a color temperature of 2360°K, which is assumed to obey the inverse square law even if the measuring instrument—the eye—has changed. These values are shown in Figure 4.

All this means that the standard for low brightness cannot be obtained from a standard at ordinary brightness levels, by mechanical reduction to these low levels of brightness, without some more or less arbitrary definition. When the question of a standard for low brightness (i.e., about 10^{-5} millilamberts) was raised in this country a few years ago, Dr. Loyd A. Jones of the Eastman Kodak

Company circulated a questionnaire to a group interested in this subject, and as a result it was decided to use a source at a color temperature of 2360°K[33] and assume that the value for the low level was given by the mechanical reduction. This is true by definition, although the summation of the products of the luminosity factors, for the eye adapted to this low brightness level, and the radiant intensity of the source, are not the same as they were at the higher brightness level, nor is the value of the standard at the low level of brightness, i.e., for the eye adapted to the low brightness is in keeping with values of the eye sensitivity shown by Figure 3. Thus if the radiant energy of a source at a color temperature of 2360°K, used to illuminate a surface at a brightness of 1 millilambert, is reduced mechanically by a factor of 10^5, the brightness of the illuminated surface would then be taken as 10^{-5} millilamberts. The brightness of a surface illuminated by a source at any other color temperature must be determined at these low levels by eye comparison with the eye adapted to this low level of field brightness, or computed on the basis of data thus taken.

As soon as this standard is selected, to find the intensity of the light from a source of any other spectral distribution, it must be compared with the selected standard by an eye adapted to this low level of field brightness. This necessity for defining the value of the low-intensity source has resulted in certain statements that are misleading. Since a field at a brightness of, say, 1 millilambert, given by a source at a color temperature of 2850°K at ordinary photometric levels, when reduced by a factor of 10^5 does not give a brightness of 10^{-5} millilamberts when compared with the defined standard, the statement is often made that light does not obey the inverse square law, or sectored-disk reduction factor for changes of this magnitude, and that such brightnesses are not additive. In reality, for transparent media, light (radiant energy) always obeys the inverse square law regardless of its color or regardless of the amount of reduction. The real trouble is that the measuring instrument has changed, as has already been shown. One might get the same sort of disappointment if he studied Ohm's law and used a galvanometer with various shunts to measure the current and forgot to make a correction for the different shunts. He would say that Ohm's law did not hold when in reality the current measurements were not made properly. Another analogy might be a study of the variation of Ohm's law with the current using a tungsten lamp as a resistance to be measured. If one forgot that the resistance in this case changed, Ohm's law would not follow.

The authors know of no present experimental evidence that, if the light given by any type of source, or by the use of any filter or combination of filters, be measured by the eye under a very definite state of adaptation, all ordinary laws of photometry are not obeyed. It must be remembered, of course, that one cannot add measurements made by the eye at different states of adaptation and that it is difficult indeed to measure light intensities, given by one field brightness, with the eye adapted to a different field brightness. As has already been mentioned, the sensitivity of the eye tends to change and one is then adding incommensurable results.

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DENISON SCIENTIFIC ASSOCIATION

Organized April 16, 1887

REPORT OF THE PERMANENT SECRETARY FOR THE PERIOD ENDING DECEMBER 31, 1945

(excluding the programs of President F. G. Detweiler's administration)

During the year 1944–45 the Denison Scientific Association had the following officers, who presided at all meetings and performed the other functions falling to their lot, *viz.*:

CHOSABURO KATO, *President*
R. M. MEYERS, *Vice-President*
J. H. GIBBUD, *Secretary-Treasurer*
W. C. EBAUGH, *Permanent Secretary and Editor*
L. E. SMITH, *Librarian*

As was now a custom, the Life Science Building formed a meeting place, unless otherwise specified. The local Granville Inn made giving a banquet an easy matter. Regular and special gatherings were addressed by the following members and friends of the Association.

September 14, 1944

HUMAN NATURE IN SCIENCE. J. K. WRIGHT (Director of the American Geographical Society)

A scholarly presentation of the aspects of geologic and geographic fields of study, with the types of work being done and contemplated, and the kind of personality engaged in investigations of geologists and geographers.

September 26, 1944

SOME NOTES ON THE GEOGRAPHY OF MICHIGAN. R. H MAHARD (Retiring President)

A comparison between the states of Michigan and Ohio in regard to geological, climatic, and agricultural productivity.

October 10, 1944

HEALTH AND CONSERVATION. JONATHAN FORMAN, M.D. (Lecturer on Allergy, The Medical School of Ohio State University)

A thriving people is dependent upon an adequate diet, and an adequate diet upon the production of proper foods, and the proper foods depend upon an agriculture dedicated to the maintenance of the vital minerals in the soil. How this is done by the selection of the output and intake of the fields was shown in the case of Ohio.

October 24, 1944

PREHISTORY OF OHIO. H. C. SHETRONE (Director of the Ohio Museum)

The various cultures of Moundbuilders extant in prehistoric Ohio, their significances, and the methods of obtaining evidence in support of the theories as to the rise and fall of these cultures, were the subjects dwelt upon with success.

November 14, 1944

THE CATHCART FERN COLLECTION. M. E. STICKNEY (Emeritus Professor of Botany)

The Cathcart Fern Collection was described, its origin, methods of collection employed, the work done, and the planning for this great lot of ferns in cataloguing them, was outlined. The importance and value of such botanical work was emphasized.

November 28, 1944

HOW MANY ANGELS CAN DANCE ON THE HEAD OF A PIN? W. W. DOLAN.

Infinities, the mathematical processes involved in dealing with transfinite numbers and other advanced subjects in the realm of higher calculation came in for their share of treatment—as an answer to the question put by the scholiasts: "How Many Angels Can Dance on the Head of a Pin?"

December 12, 1944

ELECTROSTATIC PHENOMENA ASSOCIATED WITH TIRES. J. H. GIBBUD.

Undesired electrical properties of rubbers were demonstrated and two related problems were presented. The means employed by tire manufacturers in solving their difficulties due to these properties of rubber were discussed.

January 9, 1945

UNUSUAL PROPERTIES OF GLASS FIBERS. R. B. TAYLOR (Chief Physicist, Owens-Corning Fiberglas Corporation)

The physical properties of bulk glass were listed and compared with glass in fiber form, and a comparison showed that the latter far exceeded the former for the purposes in mind. Some of the many materials made commercially out of FIBERGLAS and ordinary building substances were obtained with plastics.

January 23, 1945

FIGHTING THE BUGS. A. W. LINDSEY.

How can the continuous fight between human beings and "bugs" (as some people call all that crawl) be ameliorated? In certain instances these conditions can be improved, and by definite reactions chemically can they be changed.

March 13, 1945

PSYCHOLOGY IN INDUSTRY. L. C. STECKLE

The importance of psychology in industrial plants can scarcely be overesti-

mated. Especially is this true of the proper applications of psychological techniques to the benefits of both employer and employee.

March 27, 1945

APPALACHIAN STUDIES. F. J. WRIGHT.

Various theories advanced to account for the Blue Ridge Escarpment were brought to the attention of the group assembled. The evidence in favor of each was weighed and given due credence, and the author's interpretation was adduced.

April 10, 1945

ANNUAL DINNER OF THE DENISON SCIENTIFIC ASSOCIATION

President Chosaburo Kato presided at the annual dinner, which was held at the Granville Inn. The reports of officers and committees followed the usual pattern, and can be found in the minutes of the Secretary-Treasurer of the Association. The following were elected to the offices concerned:

R. M. Meyers, *President*
F. G. Detweiler, *Vice-President*
E. C. Rupp, *Secretary-Treasurer*
W. C. Ebaugh, *Permanent Secretary and Editor*
L. E. Smith, *Librarian*

In the program for the year 1944-1945 occurred the words in display type that formed the burden of the membership and the activities of the Association: SCIENCE EDUCATION INDUSTRY.

(Parenthetically it might be remarked that the Permanent Secretary and Editor would have not been able to perform his allotted duties without the aid of past and present members of the Association. He takes this opportunity of thanking them.)

One number of the JOURNAL OF THE SCIENTIFIC LABORATORIES OF DENISON UNIVERSITY was issued during the time covered by this report. The pages printed and the importance of the events described warrant this extra volume, if nothing else does. Contents follow, *viz.*:

Vol. 39, Article 1, pp. 1–53, June, 1945.
The Disappearing-filament Optical Pyrometer Calibration and Use; W. E. Forsythe and E. Q. Adams. 48 pp. and 18 figs.
Report of the Permanent Secretary of the DENISON SCIENTIFIC ASSOCIATION for 1944. 5. pp.
Vol. 39, Article 2, pp. 55–83, December, 1945.
Photometry: Field Brightness and Eye Adaptation; W. E. Forsythe and E. Q. Adams. 29 pp. and 4 figs.
Report of the Permanent Secretary of the DENISON SCIENTIFIC ASSOCIATION for June to December, 1945. 7 pp.

Form letters were sent out to contributors and to correspondents of the ASSOCIATION telling about the resumption of publication of our JOURNAL and the desire to be helpful in this hour of apparent need. The letter to our correspondents follows:

November 14, 1945

Gentlemen:

It is our desire to be as helpful to our correspondents throughout the world as possible, so if you will indicate upon the separate sheet the missing numbers of our JOURNAL OF THE SCIENTIFIC LABORATORIES OF DENISON UNIVERSITY, from Volume 14 to the present, an effort will be made to fill the gaps as far as our stock will permit. The new JOURNALS will be sent by the International Exchange Service of the Smithsonian Institution, Washington, D. C., or by whatever means is available at the time your order is received. There is no charge for this service. Use your good offices in bringing it to the attention of your fellow-scientists. Enclosed find a copy of the cover pages, i–iv, from our issue of June, 1945.

That we may serve our correspondents in the order in which requests are received may we ask that you attend to this matter at once, letting us known your needs after consulting your files, and write accordingly?

Of the missing numbers many of our correspondents wanted Volumes 1 to 14, which manifestly could not be given, since these copies were destroyed by fire many years ago. Others asked for all the back numbers, which (in the case of our domestic mailing list) could not be given; in the case of foreign correspondents the matter was somewhat different. Those that wanted only occasional volumes, or numbers to complete the sets already on hand, were accommodated. Letters sent to Germany, Austria and parts of Japan were returned by the postal authorities of the United States, since mail matter does not yet go to foreign enemy countries. The reply to our offer, on the whole, was gratifying, the evidence of destruction of some libraries was complete. The Belgians and Scandinavians were at the top of our list, with local offices to receive gifts and replacements.

What does the American smaller college do in the case of war? The account given by President Kenneth Irving Brown of Denison University (at DENISON, Granville, Ohio; Vol. 6, No. 3, November, 1945) answers this question in part as follows:

DENISON AND THE WAR YEARS

On October 20th the 143 trainees of our final V-12 Unit left the Denison campus. So a major chapter in Denison history is ended.

Denison has been responsible for the academic training of 1284 service men. Of these 248 were enrolled in the Pre-meteorological Training Center for the Army Air Forces Technical Training Program. The remaining 1020 were V-12 trainees, both marines and sailors. The total period of training extended from February, 1942, to October, 1945—three months short of three years. The maximum number came to us during the fall semester of 1942 when 625 service men swelled the Denison enrollment to a record figure of 1208.

Approximately one-fourth to one-third of the men enrolled in the V-12 program have indicated their intention of returning to Denison after their release from the Navy. A somewhat larger proportion has expressed a wish to be maintained on the Denison alumni rolls. Already 40 of the trainees have received their bachelor degrees from Denison—28 Navy trainees and 12 marines.

The end of an era calls for a look backward. Have the service units left any indelible impression on the campus? Has Denison learned any lessons from the war years?

The experience with our service units has thoroughly convinced the Denison faculty of the undesirability of a twelve-month program of study. Acceleration, we called it. This round-the-calendar schedule appears undesirable both for the student and for the faculty member. This is not a plea for laziness. Our colleges will do well to give careful oversight to the student experiences of the summer vacation, but in most situations an experience of

work or camp-conference or travel will better further maturity in the student than continued classroom application. And for the faculty member reasonable vacation periods with opportunity for research, study and writing are essential unless one is desiring the dull, unimaginative pedagogue.

We have learned, too, how much can be accomplished when daily work in physical training is augmented by a balanced diet and regular sleep. Probably the same measure of success is not achievable for civilian students, for even though P. T. be made compulsory and the college dietitian be equally active in peace days, the college routine for civilian students does not provide the full measure of sleep which the army discipline protected.

Furthermore, we have learned something of what can be accomplished under that same army discipline and with the incentive of officer school when the emphasis is made almost exclusively academic. The Denison trainee in the Army Air Corps, unlike his brother in V-12, was forbidden participation in any college activity—music, dramatics, athletics, fraternities. With the exception of the hours given to exercise, military drill, and the necessities of living, he was expected to devote himself almost exclusively to study. Thirty-nine hours each week he spent in the classroom and the laboratory. In addition to private study, ten hours of evening study were required with instructors sitting in attendance so that unanswered questions should not impede progress. In the space of a year the Army Air Corps trainee completed a three-and-a-half year college major in mathematics and a substantial minor in physics and in addition gained some acquaintance with English, speech history, and geography. Leisure and individual freedom were at a minimum for him; academic progress was speedy and substantial. Probably more honest-to-goodness hard brain-work was done by our 228 pre-meterologists than by any other group of Denison students in a comparable period of time. But the experience is of slight value to the college administrator, for from the civilian point of view the program omitted essential emphases and valuable experiences in the making of the whole man.

The display and even the accomplishments of military discipline have emphasized the gulf between civilian and military life. That discipline, so essential to war, appears to have little carry-over values into the years of business suits. The lesson is clear that externally-imposed discipline does not teach internally-imposed discipline; and civilian life cannot exist without the latter. One does not learn civilian punctuality under the duress of an army bugle.

There will be times ahead when social controls by military methods will seem temptingly easy, and then we of the campus will recall that the day of the student in uniform is passed for most of our colleges, and ours is the task of creating and strengthening the impulse for self-discipline.

What have we lost or gained intellectually during the years of war? Has American education "gained in seriousness but lost in mental elasticity" as *Horizon*, a British magazine, suggests of English life? Has the emotional strain of war broken our curiosity? Has it fatigued us to the point where "we are impervious, distressed, or hostile in the presence of new ideas?"

Rather for the American campus is it not true that with seriousness has come a new sensitiveness to inadequacies? It would appear that the war had enlivened our curiosity rather than dulled it. And the sense of emergency has brought a determination to do better and more wisely education's supreme and strategic tasks. Surely no other conclusion is possible as one surveys the post-war plans of the North Central colleges. And the generalization holds, I believe, for Denison.

Some of our instructors who have taught for three years without break are weary. But to all of us, even to them, the new era of peace has brought exhilaration and a consciousness of enlarged opportunity. There is so much to be done. There is so much that can be done. We shall not return with smugness to the levels of accomplishment of 1941. Rather holding fast to the best in those days, aware too of the failures of those days, and reaching forth to the larger promises which the future holds, we shall press on toward the high goals of Christian education in liberal arts, which are before us.

K. I. B.

The names in gold, numbering 50 or more, and those representing men and women in the armed forces of the United States, showing that 1500 were so employed, bear mute evidence to the devotion of our students and former students to the ideals for which their country stood and for which, if necessary, they were willing to give up life itself!

Another service of the Association was seen in returning civil service employees. One such man, a former official of the Association, gave a number of talks before local groups at Granville and Newark, Ohio; the address was reported by the NEWARK ADVOCATE of September 14, 1945 as follows:

MANY KNOW BOMB SECRET

SCIENTIST TELLS ROTARY WORLD MUST CONTROL IT

Because there is no defense against the atomic bomb, such as was used on Hiroshima last Aug. 6, civilization's only hope is in the establishment of a world organization built on common sense, that will regulate natural resources, trade, currency, immigration and a host of other matters of general world interest, J. H. Rush, former assistant professor of physics and astronomy at Denison university told members of the Rotary club at Tuesday's luncheon meeting.

Rush returned to Granville for a series of speaking engagements. He was one of the research physicists at the Oak Ridge, Tenn., plant where scientists toiled together to harness atomic energy.

"The United States has no monoply on the atom bomb secret, for the principles of nuclear physics can not be concealed from other scientists. Most of the fundamental discoveries that went into the creation of the atomic bomb were the result of research by eminent scientists from other countries. In this instance the research men had the financial backing of the United States government," he said.

"Effective world authority should be created to oversee atomic developments in all nations to regulate the uses of atomic energy and to prevent the manufacture of atomic bombs to destroy civilization," he said.

Actually, the scientists in Nazi Germany developed the idea but the Nazi army leaders were not interested enough to provide the necessary financial backing for carrying the undertaking to completion. Some of these scientists as refugees from Nazi Germany gave valuable assistance in helping the Americans produce the bomb that hastened the end of the war.

As reported by L. E. Smith, the Librarian of this Association, the public appearances of J. H. Rush were occasions for his addresses as follows:

Mr. J. H. Rush, Assistant Professor of Physics 1942–1944, now of the Clinton Laboratories, Oak Ridge Tennessee, gave a series of talks concerning the social and political implications of the Atom Bomb. His first talk was before the FORUM on Sunday evening, December 9. He spoke in Chapel on Monday, December 10 using for his subject, "Christmas in an Atomic Age." On Monday evening he spoke again to students, and later in the evening to the Faculty. Tuesday's talks were addressed to the Granville High School and to the Rotary Club of Newark. In every instance, Mr. Rush was concerned with the social and political side of this development. He represents the Federated Atomic Scientists who are especially interested in public understanding of the present situation and in developing a public opinion and world concern. It is held that we as the developers of this mighty weapon do not possess any basic new idea, but only the technique of the production of it. This advantage will soon disappear as others work on these same problems. The responsibility of a World Consciousness of and concern for the general welfare of all the peoples of the World rests heavily upon us. We must aggressively take the lead in some sort of a World Organization that can be trusted and that can be powerful enough to make

further Wars impossible. The plea for justice and consideration and understanding of all peoples and their problems was made very strong. He carefully pointed out that these scientists hoped to gain no political or other advantage other than the welfare of all mankind.

With the coming of peace and its inevitable turning from things of war, the colleges of America go back to their prewar occupations primarily to preserve the past, advance the knowledge of the future, and train men and women to take their places as good citizens of their country. The "speeded up courses" soon will fade from the picture, the returning service men and women will make their influence felt, and the long row ahead will be a reality for teachers and students alike.

Respectfully submitted,

W. C. EBAUGH, *Permanent Secretary and Editor*

Ordovician and Silurian of American Arctic and Subarctic Regions; Aug. F. Foerste. 54 pp., 2 plates.
Location Factors in the Iron and Steel Industry of Cleveland, Ohio; Charles Langdon White. 16 pp., 4 figs., 1 plate.
A Photographic Record of the Total Eclipse of the Moon; Paul Biefeld. 2 pp., 1 plate.
Basslerina, A New Holliniform Ostracode Genus, with Description of New Pennsylvanian Species from Texas and Oklahoma; Raymond C. Moore. 15 pp., 3 plates.

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Some Proparia from the St. Clair Limestone, Arkansas; Norman L. Thomas. 14 pp., 2 plates.
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A Large Fish Spine from the Pennsylvanian of North Central Texas; Raymond C. Moore. 7 pp., 1 plate.
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Stream Piracy near Asheville, N. C.; Frank J. Wright. 6 pp., 1 fig., 1 plate.
Motor Vehicle Transportation Cost and its Relation to Highway Finance; Bruce D. Greenshields. 6 pp., 1 fig.

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A Study of the Change in Mass of the Anode of the Aluminum-Lead Cell; Charles E. Welling. 5 pp.
Balancing Chemical Equations—The Contribution of Otis Coe Johnson (1880); W. C. Ebaugh. 4 pp., 1 plate.

Article 4, pp. 155–248; October, 1933.....$1.00
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Evidence of Ice Action in the Teays Valley, West Virginia; Julian J. Petty. 10 pp., 4 figs.
The Earlier History of the BULLETIN OF THE SCIENTIFIC LABORATORIES OF DENISON UNIVERSITY; Aug. F. Foerste. 23 pp.

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Articles 1–2, pp. 1–118, April, 1935.....$1.00
Big Horn and Related Cephalopods; Aug. F. Foerste. 96 pp., 22 plates.
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Article 3, pp. 93–142, August, 1936.....$1.00
The Newer Appalachians of the South (Part II): South of the New River; Frank J. Wright. 50 pp., 6 figs., 32 plates.

Articles 4–6, pp. 143–259, December, 1936.....$1.00
A Study of the Vestigial Air Bladder in the Darter (*Catonotis flabellaris rafinesque*); George David Morgan. 16 pp., 10 plates.
We Must Shape our New World (Commencement Address); Arthur Holly Compton. 11 pp.
Later History of the JOURNAL OF THE SCIENTIFIC LABORATORIES OF DENISON UNIVERSITY; Kirtley F. Mather. 25 pp.
Report of the Permanent Secretary of the DENISON SCIENTIFIC ASSOCIATION. 52 pp.

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New Ostracodes from the Clore Formation, Carey Croneis and Harold J. Funkhouser. 29 pp., 2 plates.
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Some Factors Affecting the Operation of Incandescent Lamps; W. E. Forsythe, E. Q. Adams, and P. D. Cargill. 27 pp., 7 figs.
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New Crinoids from Upper Pennsylvanian and Lower Permian Rocks of Oklahoma, Kansas, and Nebraska; Raymond C. Moore. 109 pp., 39 figs., 5 plates.
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The Relative Efficiency of Single Versus Multiple Exposures in the Rapid Memorization of Visual Forms; L. C. Steckle. 31 pp., 7 figs.
New Genera of Pennsylvanian Crinoids from Kansas, Oklahoma and Texas; Raymond C. Moore. 23 pp., 9 figs., 1 plate.
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Relationships of the Family Allagecrinidae, with Description of New Species from Pennsylvanian Rocks of Oklahoma and Missouri; Raymond C. Moore. 83 pp., 14 figs., 2 plates.
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Conodonts from the Keokuk Formation; E. B. Branson and M. G. Mehl. 10 pp., 1 plate.
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The Recognition and Interpretation of Mixed Conodont Faunas; E. B. Branson and M. G. Mehl. 15 pp.
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Tegminal Structure of the Pennsylvanian-Permian Crinoid *Delocrinus*; Raymond C. Moore and Harrell L. Strimple. 12 pp., 1 plate.
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Dakotasuchus Kingi, A Crocodile from the Dakota of Kansas; M. G. Mehl. 19 pp., 3 figs., 2 plates.
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What Students Want in an Instructor; L. C. Steckle. 4 pp.
Chemistry and Modern Laundry Practice; Earl R. Haynes. 63 pp., 3 figs.
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Illinoian Glaciation in Killbuck Valley South of Millersburg, Ohio; George D. Hubbard. 11 pp., 1 fig.
Biological Sociology; Alfred Edwards Emerson. 10 pp.
The Life Science Building at Denison University; Arthur Ward Lindsey. 4 pp., 1 fig.
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Blastoids from Middle Pennsylvanian Rocks of Oklahoma; Raymond C. Moore and Harrell L. Strimple; 7 pp., 1 fig.
A New Species of Synbathocrinus from Mississippian Rocks of Texas, with Description of Ontogeny; Raymond C. Moore and John D. Ewers. 15 pp., 28 figs.
Mercury Vapor Lamps; W. E. Forsythe, E. Q. Adams and B. T. Barnes. 26 pp., 20 figs.
Articles 8-9, pp. 133-163, December, 1942.....$1.00
Geography in a World at War; C. Langdon White. 7 p.
The Meaning of Science in Human Affairs; C Judson Herrick. 13 pp.
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Establishing and Maintaining a Color Temperature Scale; W. E. Forsythe and E. Q. Adams. 31 pp., 9 figs.
The Vegetation of Idaho; R. Maurice Myers. 8 pp., 1 fig.
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Radiometric and Colorimetric Characteristics of the Blackbody between 2800°K and 3800°K; E. Q. Adams and W. E. Forsythe. 17 pp., 1 fig.
Report of the Permanent Secretary of the DENISON SCIENTIFIC ASSOCIATION. 8 pp.

VOLUME 39

Article 1, pp. 1–54, June, 1945.....$0.75
The Disappearing-filament Optical Pyrometer Calibration and Use; W. E. Forsythe and E. Q. Adams. 48 pp. and 18 figs.
Report of the Permanent Secretary of the DENISON SCIENTIFIC ASSOCIATION for 1944. 5 pp.
Article 2, pp. 55–90, December, 1945.....$0.75
Photometry; Field Brightness and Eye Adaptation; W. E. Forsythe and E. O. Adams. 29 pp. and 4 figs.
Report of the Permanent Secretary of the DENISON SCIENTIFIC ASSOCIATION for June to December, 1945. 70 pp.